STATEWIDE SURVEY OF BLOWUPS IN RESURFACED CONCRETE PAVEMENTS

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BY

PAUL T. FOXWORTHY

JHRP

JOINT HIGHWAY RESEARCH PROJECT
PURDUE UNIVERSITY AND
INDIANA STATE HIGHWAY COMMISSION

Interim Report

STATEWIDE SURVEY OF BLOWUPS IN RESURFACED CONCRETE PAVEMENTS

TO: J. F. McLaughlin, Director
Joint Highway Research Project

February 8, 1973

Project: C-36-460

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

File: 5-11-15

Attached is an interim report prepared by Mr. Paul Foxworthy summarizing the field survey made of blowups in resurfaced concrete pavements. This report also presents a preliminary analysis of the data.

A survey was made of all of the resurfaced concrete pavements in the State of Indiana. The extent of blowups was determined by driving over the pavements and counting and classifying the blowups. The statistical analyses have suggested trends in the data, but additional work needs to be accomplished before definite conclusions are drawn.

This is an interim report and a final report covering the field study will be submitted at a later date.

Respectfully submitted,

Harold L. Michael

Harold L. Michael
Associate Director

HLM:ms

cc: W. L. Dolch
R. L. Eskew
W. H. Goetz
M. J. Gutzwiller
G. K. Hallock
R. H. Harrell
M. L. Hayes
C. W. Lovell
G. W. Marks
R. D. Miles
J. W. Miller
G. T. Satterly
C. F. Scholer
M. B. Scott
J. A. Spooner
N. W. Steinkamp
H. R. J. Walsh
E. J. Yoder

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16. Abstract

The purpose of the study was twofold. The first purpose was to catalog the blowup activity on all the resurfaced pavements in the State of Indiana. The second purpose was to determine the cause of blowup activity.

The results have suggested that a major contributor is the original pavement design, but this factor is confounded by pavement age. Pavements with a granular base course had more blowups than those that did not, and use of paved shoulders has apparently reduced the problem. A high degree of correlation in blowup activity and geographic location in the state was shown. Those highway districts containing high population centers had more blowups than those with less population. Additional work needs to be done to clarify the results presented in the interim report.

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STATEWIDE SURVEY OF BLOWUPS IN RESURFACED CONCRETE PAVEMENTS

by

Paul T. Foxworthy
Graduate Assistant in Research

Joint Highway Research Project

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The author extends special thanks to his wife for her assistance in typing the rough and final drafts of this study and her patience during the course of the study.

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Foxworthy, Paul Thomas. M.S.C.E., Purdue University, May, 1973. STATEWIDE SURVEY OF BLOWUPS IN RESURFACED CONCRETE PAVEMENTS. Major Professor: Eldon J. Yoder.

The purpose of this study was two-fold. The first objective of the study was to collect information concerning rigid pavements in the Indiana system of highways. This information has been processed for computer use which makes rapid and easy retrieval possible.

The second purpose of the study was to make a preliminary analysis of the factors which are important contributors to blowups in resurfaced concrete pavements. This information should allow highway officials to predict the reaction of concrete pavement to resurfacing.

The results of this study have indicated that, in so far as blowup occurrence in concrete pavements resurfaced with asphalt is concerned, (a) age of the pavement is a major contributing factor; pavements built since 1959 had fewer blowups per mile than older pavements, (b) the source of coarse aggregate for concrete pavements influences blowup activity as does type of aggregate used, (c) little difference exists between soil types in contributing to the blowup problem, (d) paved shoulders significantly reduced

blowups, (e) blowups generally begin to appear two years after the first resurface is applied, and (f) there was poor correlation between blowup occurrence and overlay thickness.

INTRODUCTION

Blowups of portland cement concrete pavements have been a problem encountered by most state highway agencies throughout the United States for many years. Although blowups are detrimental to the riding quality of a pavement and sometimes hazardous to the road user, their occurrence has been greatly reduced through design and specification changes resulting from intensive research into the problem.

With the advent of a major resurfacing program for upgrading deteriorating portland cement concrete pavements, blowups have again become a problem. Although individually not as severe a blowup as in concrete pavements, a blowup on resurfaced concrete occurs so much more frequently that it poses a major problem. Expensive corrective measures are often required to completely alleviate the problem, the result being that temporary measures are widely used which satisfy the public at lower cost, but do not eliminate the problem completely.

Many thousands of miles of interstate, state, and local roads will need resurfacing in the near future. Hence, there exists a great need for investigating the blowup phenomenon to determine its extent, probable causes, and possible solutions.

BACKGROUND INVESTIGATION

Mechanics of Blowups

Blowups are caused by compressive stresses resulting from heat and water and generally occur at a joint or crack. Similarly, intrusion of foreign material and chemical de-icing solutions into joints and cracks causes extensive damage to rigid pavements. Cook and Lewis (2) state, "The intrusion of incompressible soils into the joint space causes even greater problems. Joints filled with solids are unable to close properly; consequently, extremely high stresses are built up within the slabs. Because of the uneven nature of the solid material that has infiltrated into the joint, non-uniform concentrated stresses in the concrete adjacent to the joint opening ultimately results in spalling and progressive disintegration of the concrete." Because of the restrained movement, "the compressive stresses may be relieved by a blowup in which a portion of the slab breaks away and moves upward, or the entire slab may translate." This upward movement ranges from a fraction of an inch to more than a foot in extreme cases.

Engineers in New York (3) have identified two major classes of blowups in rigid pavements. The first type of blowup occurs typically in unresurfaced concrete pavements

and is usually a buckling and/or shattering (sometimes violently) of two adjacent pavement slabs.

The second type occurring primarily in resurfaced concrete pavements, is commonly referred to as "bumps", "humps", or "high joints". This latter type of blowup is apparently the result of compression and upward extrusion of deteriorated concrete rubble, which, had it remained sound, probably would have accommodated the compression. Vertical displacements up to three inches are not uncommon. While not a serious hazard to traffic, the second type of blowup detracts considerably from the riding quality of the pavement and generally requires considerable maintenance.

While the first type of blowup is easily recognizable and distinct in appearance, the second type can often resemble other pavement failures such as faulting in resurfaced pavements. The mechanisms of the second type are unique, however, and present problems entirely its own.

History of Design of Concrete Pavements in Indiana

Since the formation of the Indiana State Highway Commission, designers and researchers have constantly strived to enhance the performance of rigid pavements. Results of the research have led to many changes in both the physical design and the specifications used in construction of Indiana's highways. Table 1 outlines the history of concrete design changes in Indiana. It is hoped that a knowledge of the performance of each design will provide

Table 1. Summary of Pavement Design Changes in Indiana

Period	Pavement		Expansion Joints		Contraction Joints		Steel Reinforcement			Remarks
	Wd.	Thick.	Type	Spacing	Type	Spacing	Type	Size	Spacing	
Prior to 1923	18	6-8-6 7-8-7								Plain Pavements
1923 to 1925	18	7-7-7 8-8-8					Marginal Bars Transverse Bars	3/4" 1/2"	17' 4'	
1926 to 1933	18 & 20	7-7-7 9-7-9	Doweled	50' from bridge			Marginal Bars Tie Bars	3/4" 5/8"	17-19' 5'	3/4" Dowels Spaced 1' Apart
1934 to 1940	20	9-7-9	Doweled	80' 100' 120'	Doweled	80' 33' 40'	Tie Bars Temperature Wire	1/2" #6 lg. #6 tr.	5' 6" 12"	80' Expansion Joints Alternate With 80' Contraction Joints
1941 to 1944	22	9-6-9 9-7-9 9-8-9	Undoweled	120'	Undoweled	20'	Tie Bars	5/8"	5'	

Table 1. Continued

Period	Pavement		Expansion Joints		Contraction Joints		Steel Reinforcement			Remarks
	Wd.	Thick.	Type	Spacing	Type	Spacing	Type	Size	Spacing	
1945 to 1949	22	9-7-9			Doweled	40'	Tie Bars Tempera-ture Wire	5/8" #6 lg. #6 tr.	5' 6" 12"	Coarse Aggregate Specifications Tightened
1950 to 1959	24	9-9-9			Doweled	40'	Tie Bars Tempera-ture Wire	1/2" #2 lg. #4 tr.	2 1/2' 6" 12"	Changed to 1 1/4" Diameter Dowels
1960 to Present	24	10-10-10 Variable Cont. Rein.			Doweled	40'	Tempera-ture Wire	#2 lg. #4 tr.	6" 12"	

clues as to the probable causes of type two blowups.

Prior to the formation of the Highway Commission in 1919, the responsibility for construction of highways in Indiana rested with the counties. During those early years of construction, very little was known about the stresses in rigid pavements resulting from loads and expansion of the concrete. Pavements were generally 16 feet wide with various thickness and contained no reinforcing steel or joints to control expansion.

In 1923 the ISHC developed their first pavement design standard, which included No. 6 longitudinal marginal bars as well as No. 4 deformed bars placed transversely at four foot centers. Placed directly on the subgrade, this pavement was 18 feet wide with a seven inch uniform thickness. This standard design remained unchanged until 1926, when the need for a longitudinal joint became apparent. Designers thus revised the original 1923 standard, deleting the transverse bars and adding a longitudinal joint tied with No. 5 bars spaced five feet on centers. The concept of the thickened edge pavement to relieve edge stresses was also incorporated into the standards with the first 9"-7"-9" pavement for high traffic roads.

The period from 1926 to 1934 saw the previous design concepts used in all pavements constructed by the State with one exception. Pavement expansion was, in some cases, causing severe distress at bridge abutments. Consequently, expansion joints three inches wide, filled with bituminous material, and doweled with No. 6 bars spaced three and one

half feet on centers, were specified 50 feet from each bridge abutment. This particular change constituted the first transverse joint used to relieve compressive stresses and partially control blowup activity. In cases where heavy traffic was anticipated, pavements were thickened to eight inches and widened to 20 feet.

By 1934 it became apparent that expansion joints at bridges alone could not control contraction and restraint cracking and blowups. Therefore, expansion and contraction joints, alternating at 40 foot spacings and with No. 6 dowels, were introduced into the standards. Other changes made in 1934 included the use of temperature steel to control the extent of crack openings, the deletion of marginal bars, and the establishment of the minimum pavement width at 20 feet.

A major change in the design of highways constructed of reinforced concrete was made in 1941. First, the increase in the demand for steel for armament purposes forced designers to limit its use in concrete pavements to longitudinal tie bars only. Secondly, designers realized that load transfer across joints with no dowels would have to be accomplished through grain interlock, and thus the contraction joint spacing was reduced to 20 feet to limit crack opening. Undoweled expansion joints were spaced at 120 feet. Finally it was during this period that the use of the 22 foot wide pavement became popular to accommodate increased truck traffic.

The year 1946 marked the resumption of pre-war design practices with two major exceptions. Specifications were amended to require the laying of a granular subbase under the pavement and the deletion of expansion joints. Both changes were made as a result of research into the pumping problem which had become severe at this time. The "trench" design for subbases was used at first. Subsequent designs extended the subbase through the shoulder to provide better drainage, with subdrains first extensively used about 1951.

Woods, Sweet, and Shelburne (18) made a study of the effect of coarse aggregate on blowup occurrence, and subsequently, Indiana put stricter control on the coarse aggregate used in concrete paving. Several sources of aggregates considered as primary causes of blowups were eliminated as a result of this study. During the period 1946 to 1957, pavements were widened to 24 feet with uniform thicknesses of nine inches. Temperature steel was increased in size to No. 2 wires longitudinally and No. 4 wires transversely, and tie bars were reduced to No. 4 bars spaced two and one half feet on centers. In 1957 the size of dowel bars was increased to one and one fourth inches in diameter.

Pavement design remained unchanged until the mid 1960's when ten inch thicknesses were introduced, as well as continuously reinforced concrete pavements. Constructed without joints and with high steel percentages, this latter type of pavement is designed to minimize maintenance, but more time is needed to evaluate its performance. This is especially true

with regard to bituminous overlays, since presently there are no resurfaced continuously reinforced concrete pavements.

Factors Influencing Blowup Activity

The immediate cause of a blowup, as was pointed out earlier, is a buildup of compression stresses in a concrete pavement which have been concentrated into a small area. Such a buildup of stresses is most likely a result of a combination of several factors.

Temperature

The summary of a study on pavement blowups in Arkansas (7) states, "Blowups seem to be caused by a combination of temperature and moisture in the concrete slab." Graham (5) in New York reports, "The consensus among the County Resident Engineers was that the cause of pavement blowups is high temperatures." This study also showed that over 80 per cent of blowups investigated occurred at ambient temperatures in excess of 90 degrees. Similar findings were reported in the Illinois study (8) and the British study (15).

Researchers from Connecticut (1) drew an interesting conclusion stating that, "The temperatures at which adjacent lanes are placed may influence pavement performance. High uniformity of placement temperatures between lanes results in low frequency of failure. Conversely, a large spread between the placement temperatures in adjacent lanes gives rise to high frequency of failure." The Engineering News Record (11), in reporting results of a study in Delaware

nearly 50 years ago stated, "The most frequent occurrence of blowups is when a hot day is followed by a rainy night succeeded by another hot day, causing temperature and moisture expansion." Not only do high temperatures significantly affect blowup occurrence, but low temperatures cause pavement contraction and subsequent opening of the joints, which can result in the infiltration of foreign matter into joints. This aspect will be discussed later in further detail.

Moisture

As previously stated, moisture in combination with temperature is a major contributor to blowups. However, in work concerning concrete resurfacing with concrete (10,4,17), the cause of increased blowup activity was probably not due to an increase in temperature, but was most likely due to increased moisture content. Gotham and Lord (4) found a "flowing film of water" at several places between the two layers of concrete.

The importance of moisture is also pointed out in the Arkansas study (7) when maintenance forces found that the bottom portion of each slab where a blowup had occurred was saturated. Illinois (8) reported that 75 per cent of all blowups were found to have occurred within a week following a rainfall. Sweet (13) showed that freezing and thawing, obviously dependent on the presence of moisture in the form of snow as well as rain, reduced aggregate strength with subsequent deterioration of the concrete and an increase in blowups.

Aggregates

In Indiana, major emphasis has been placed on correlating types of aggregates, primarily coarse aggregates, with blowup occurrence. Woods, Sweet, and Shelburne (18) found an outstanding correlation between certain coarse aggregate sources and blowup susceptible pavements. Conversely, certain sources distinctly lacked any connection with blowup activity. In the conclusion of their study, Sweet and Woods (14) stated, "Aggregate has an important influence on the durability of concrete." The British researchers (15) found that the use of expansive and unsound aggregates considerably increases the number of blowups. Similar findings were reported by Sweet (13). It must be pointed out, however, that the Illinois study (8) found no correlation between source of coarse aggregate and blowups, but the possibility was not ruled out.

Woods et al (18) found no significant difference between gravel and crushed stone as contributors to blowups, but Maryland (16) found "....pavements having gravel aggregate had a higher average frequency of apparent end failures (repaired blowups) ....than did pavements with either stone or slag aggregate." Sweet and Woods (14) state, "The grading, particle shape, and surface characteristics of the fine aggregate have a marked influence on durability of pavements." Generally speaking, however, no correlation has ever been established between the type of aggregate and blowups or between type of cement and blowups.

Age of Concrete

In most research conducted on blowups, age of the concrete has been considered to be a major variable, but as yet no definite relationship has been established. According to Stott and Brook (15), "It appears that the frequency of blowups increases with age of the road, although there is not sufficient evidence to establish a definite relationship. Generally a road is three to nine years old before blowups begin to occur, although some cases were reported where the road was only about one year old." Arkansas (7) reported that blowups start occurring about four years after construction, while the British (15), Illinois (8), and Maryland (16) studies took the age factor directly into account using the measured variable of blowups per mile per year. Illinois tried to relate age to blowups by looking at changes in pavement design. However, difficulty in assigning blowups to a particular design arose because such changes were made gradually.

Joints

Several aspects of joints in concrete pavements have a direct influence on the occurrence of blowups, including: (1) the presence or absence of expansion joints, (2) the spacing between joints, (3) infiltration of grit into joints, and (4) faulty joint construction and/or operation. In regard to the first point, Stott and Brook (15) concluded, "The evidence obtained does not make it possible to be

specific on the effect of omitting expansion joints from concrete roads. Experience in the United States indicates that blowups have occurred on concrete roads whether or not expansion joints were used."

Concerning joint spacing, some state engineers were of the opinion that shorter joint spacing of contraction joints made blowups less likely because joint movements were less. Research in Maryland (16), Illinois (8), Connecticut (1), and Arkansas (7) substantiate this conclusion. Stott and Brook (15) also made the same observation.

Many engineers feel that a major cause of blowups is infiltration of incompressible material into joints and cracks. Unsatisfactory performance of sealing compounds is the primary reason for infiltration (15). One conclusion is that blowups occur because incompressible material lodging in open joints and cracks restricts subsequent expansion and causes disruptive stresses (3). Actual inspections of blowups in Arkansas (7) and New York (5) showed that base material was mixed with the deteriorated concrete at the joint. Joint failures themselves do not preclude other mechanisms also coming into play (6). Pumping is a major contributor to joint infiltration.

Few engineers hold the opinion that faulty construction of joints other than expansion joints is a serious cause of blowups. The Bureau of Public Roads in 1968 has expressed concern, however, that corrosion of dowel bars reduced load transfer at joints (15). Structural weaknesses that develop

at expansion joints have proven discouraging to their use (8). On the other hand, expansion joints are used extensively in New Jersey with great success.

Subgrade Soil

Walbeck and Stromberg (16) in Maryland did some extensive investigations into the effect of subgrade soils on blowups, grouping soils into three general classes: sandy, silty, and clay. With respect to end failures (repaired blowups) Walbeck and Stromberg found that sandy soils had the worst performance, followed by silty soils, and finally clay soils, which gave the best performance. From a moisture standpoint, the clay soils should perform least satisfactorily, suggesting that other variables, possibly infiltration, are more important.

Hensley (7) concluded in the Arkansas study that, "Blowups occurred more frequently where the pavement was laid over a moderately permiable subgrade, which had a medium-high plasticity index." Conversely, Illinois (8) found that subgrade soil was insignificant. Finally, Woods et al in Indiana (18) stated, "Soil is not a significant factor in the susceptibility of a pavement to blowing up, this failure having occurred in a wide range of soil texture. However, disintegration of those pavements susceptible to blowups was more rapid on plastic soils than on the more granular types."

Bases

Several past studies on blowups have attempted to relate the type of base material used to blowup activity. None of these studies has shown this to be significant.

Traffic

Woods, Sweet, and Shelburne (18), while discussing traffic as a factor, state, "The effect of traffic has been observed to be secondary in nature. Blowups have occurred on both lightly and heavily traveled roads. Conversely, many roads built before 1935 and subjected to wide ranges of traffic conditions are without blowups. However, it has been observed that on highways where blowups are prevalent, accompanying concrete deterioration is more severe on the heavily traveled roads." In the studies in Maryland (16) and Illinois (8), traffic, by itself, was not found to be significant, but in conjunction with age, it became so. An interesting observation was made by Bowers (1) in the Conneticut study when he states, "Pavements with two lanes, where lane distribution is more uniform, tend to have lower rates of compression failures."

PURPOSE AND SCOPE

The overall project is divided into two phases. Phase One, of which this report is a part, consists of making a statewide survey of resurfaced concrete pavements and an analysis of factors which influence blowup activity.

Phase Two of the project, which combines field and laboratory studies, will compare samples of concrete taken from selected field test sections, with samples made in the laboratory. This comparison will involve thermal, chemical, and mechanical properties of concrete. These materials properties will be related to measured strains experienced by concrete in the field in an attempt to predict the strain any pavement will undergo. If this predicted strain is greater than the estimated allowable strain, the pavement will be susceptible to blowups. Measures can then be taken to increase the allowable strain in the pavement to prevent blowup occurrence.

As stated earlier, the research reported herein is part of Phase One of the project, with the primary purpose to obtain and analyze field data to find what major factors influence blowup activity. This study consisted of a statewide survey of all resurfaced concrete pavements in Indiana, with subsequent coding and storage of this data for

future use. This report presents a preliminary analysis of the field data. Further study of the field data will be necessary to complete the investigation for Phase One. Suggestions for this continued study will be brought out throughout the report.

PROCEDURE

Records Survey

All of the resurfaced concrete pavements in the rural system of state and federal highways in Indiana made up the survey population. This population was then subdivided into basic units or sections. Road-life records maintained by the ISHC provided the key to the breakdown of the system into manageable sections. These records include a history of every major piece of construction performed for any given highway in the state system.

From the Road-life records, it was decided that the optimum breakdown of a road could easily be made on the basis of uniform sections with regard to dates of construction of the original concrete and of all overlays. Thus, a basic section consisted of a piece of road at least one tenth of a mile long in which all concrete was poured under the same project, the same number of overlays existed throughout the section, and each overlay was laid under the same project. If any of the above three conditions changed along a highway, a new section was established.

A large variety of factors that were believed to influence blowup activity as established by past research findings were catalogued. This was done not only for

purposes of the study, but also for general reference information to be kept on permanent magnetic tape storage. Table A1 gives a complete list of the factors taken into consideration, how they are coded on tape, and how they were obtained.

Field Survey

The field survey portion of the study consisted of counting the number of blowups in each section of highway, determined from the records survey. Ten different categories of pavement distress were identified on the basis of the severity of the blowup and the type of maintenance performed on repaired ones. Five basic distress types shown in Table 2 were further subdivided according to whether they extended across just one lane or whether they extended across two lanes. Hence, twice the number (or 10) types of distress shown were logged. Further, these distress types were not physically measured, but were classified by the survey team while riding in a car. Figures 1 through 5 illustrate the distress categories listed in Table 2.

In addition to recording the cumulative total of blowups for each mile, subjective information regarding the overall drainage characteristics and the type of shoulder on the section was recorded. The entire field survey covered over 3400 miles of rural highway.

Table 2. Types of Blowups and Other Features Counted During the Field Survey

Type of Distress	Description
Type 1 Blowup	Equal to or less than about 1" in height and less than about 2" wide
Type 2 Blowup	Greater than about 1" in height and generally greater than 2" wide
Type 1 Patch	Equal to or less than about 2' wide
Type 2 Patch	Greater than about 2' wide
Type 3 Blowup	Heated and planed joint

Figure 1. Type One Blowup

Figure 2. Type Two Blowup

Figure 3. Type One Patch

Figure 4. Type Two Patch

Figure 5. Type Three Blowup

Data Analysis

The third major step of this study consisted of analysis of the information collected in the records survey and the field survey. For purposes of the statistical analysis, it was decided that types 1, 2, and 3 blowups should be added together to form a total for a particular section. This total was then divided by the length of the section to give units of blowups per mile for the dependent variable. The patches, although probably some type of blowup at one time, were not included in the data analysis due to their uncertain history.

One of the primary aims of this study was to establish procedures by which it might be possible to predict whether a given road will blow up if overlaid. A regression model was first developed. Such an equation would give state highway officials an estimate of the number of blowups per mile that could be expected on a particular road if it were overlaid. Unfortunately, the model that was evolved explained only 17 per cent of the variation in the data ($R^2 = .17$) and hence, was considered to be of little value.

The second approach to the problem took the form of an analysis of variance. This type of analysis would show what factors were important in contributing to the number of blowups per mile. However, due to the large number of samples and subsequent limitations of the computer, all of the factors involved could not be considered simultaneously in

the analysis of variance. As a result, this analysis was not very useful.

The analysis which was used consisted first of a breakdown of the total miles of road into three blowup groups: Group 1, roads for which no blowups were recorded; Group 2, roads containing some blowups but less than four per mile; and finally Group 3, roads with four or more blowups per mile. Next, each of these groups was divided according to levels for every factor. Finally, per cents of total miles for a given level, divided into the three blowup groups, were computed.

The final step in the analysis of data consisted of a statistical investigation of those factors found to have a substantial difference in per cents among levels, in order to substantiate any conclusions drawn. The Scheffe' Test for differences of means was used for this purpose. To complete this test, the assumption of homogeneity of variance among levels for every factor was satisfied by taking the square root of the dependent variable, the number of blowups per mile. Using this transformed variable, the mean number of blowups per mile for each level of the factors analyzed was computed. One level (i) was declared significantly different over another level (j) if:

$$| \bar{Y}_i - \bar{Y}_j | > \sqrt{(k - 1)\, F_{\nu 1, \nu 2, \alpha}} \sqrt{s^2 \, (1/n_i + 1/n_j)}$$

where: $\bar{Y}_i$ = the mean for level i

$\bar{Y}_j$ = the mean for level j

k = the total number of levels of the factor

F = the F statistic

ν_1 = the degrees of freedom = $k - 1$

ν_2 = the degrees of freedom = $\sum_{i=1}^{k} n - k$

α = level of the test = .05

s^2 = pooled estimate of the variance

n_i = number of observations for level i

n_j = number of observations for level j

n = total number of observations

The results of this test are summarized in Table A4 and will be discussed simultaneously with the important factors.

RESULTS

Twenty-two factors were originally considered to be possible causes of blowups. Nine of these factors were shown to be significant in this study. In the discussion of each of these nine factors, appropriate tables will be presented to illustrate each point. It should be pointed out that mileages among levels differ substantially, thus affecting the conclusions made to a degree.

Pavement Design

The variable of pavement design was divided into the eight levels according to Table 1. For this analysis the first three levels were combined into one because of their similarities in design. The last level in Table 1 is not included in the analysis since there are no overlaid pavements less than 12 years old.

To illustrate how the data were organized for analysis, from Table 3 it can be seen that 3410.2 miles of road were included in the study. By examining level three, it is apparent that 210.6 miles of road were constructed during the period 1941-1944. Of the 210.6 miles in level three 73.8 miles or 33.9 per cent had more than four blowups per mile. The percents for each level total 100 per cent horizontally.

Table 3. Effect of Pavement Design* and/or** Year Constructed on Blowups

Level	Year Constructed	Miles of Road: No Blowups	Miles of Road: <4 Blowups Per Mile	Miles of Road: ≥ 4 Blowups Per Mile	Miles of Road: Total Miles	Per Cent of Miles: No Blowups	Per Cent of Miles: <4 Blowups Per Mile	Per Cent of Miles: ≥ 4 Blowups Per Mile
1	1919-1933	288.0	908.4	1158.0	2354.4	12.2	38.6	49.2
2	1934-1940	112.0	331.6	222.0	665.6	16.8	49.8	33.4
3	1941-1944	21.9	114.9	73.8	210.6	10.4	54.5	35.1
4	1945-1949	33.1	93.1	22.1	148.3	22.3	62.8	14.9
5	1950-1959	12.7	16.5	2.1	31.3	40.6	52.8	6.6
					3410.2			

* See Table 1 for designs and years

** and/or indicates confounding of Pavement Design and Year Constructed; where "confounding" is defined generally as "The effect of one factor is not distinguishable from that of another factor or factors". For example, the effect of Pavement Design on number of blowups is not distinguishable from the effect of Year Constructed on number of blowups.

From Table 3 it can be seen that, in a general trend, the per cent of miles of roads with no blowups increased as changes in design were made. Similarly, the per cent of miles of road with four or more blowups per mile decreased, reflecting the overall effectiveness of these changes on pavement performance. Almost 50 per cent of the roads built prior to 1933 now contain more than four blowups per mile, while nearly 41 per cent of the pavements built since 1950 have no blowups.

The undoweled, short-jointed pavements built during World War II demonstrate slight departures from the previous trends, since they showed a great amount of blowup activity, suggesting that steel reinforcement is beneficial and/or close spacing of joints detrimental to blowup prevention. These two conditions act together and cannot be discussed independently. Results of the Scheffe' Test in Table 4b substantiate this conclusion by showing that pavements built during the period 1941-1944 have the highest mean number of blowups per mile, followed by pavements built before 1933 with the second highest mean.

Changes in design have reduced the severity of the blowup problem, but they did not eliminate it. This is evidenced by the increase in the per cent of miles of road with less than four blowups per mile. It should be noted that concrete age is confounded with pavement design, thereby affecting any conclusions made. This confounding needs further investigation to determine its effect on reducing blowups.

Table 4a. Ranking of Means (Pavement Design and/or Year Constructed) for Scheffe' Significance Test

Level	Mean Number of Blowups Per Mile	Number of Observations	Standard Error of the Mean
3	2.0128	93	.1710
1	1.8227	746	.0494
2	1.3270	248	.0784
4	0.9379	57	.1263
5	0.8161	18	.2265

Table 4b. Results of Scheffe' Significance Test for Effect of Pavement Design and/or Year Constructed

i	j	$Y_i - Y_j$	"C" Factor	Significant
3	5	1.1967	1.0545	x
3	4	1.0749	.6888	x
3	2	.6858	.4979	x
3	1	.1901	.4503	
1	5	1.0066	.9768	x
1	4	.8848	.5627	x
1	2	.4957	.3001	x
2	5	.5109	.9996	
2	4	.3891	.6015	
4	5	.1218	1.1071	

Base

In 1946 the Indiana State Highway Commission changed its specifications for construction of concrete pavements to provide a granular base beneath each pavement. The effects of this factor are shown in Table 5.

A base is shown to be beneficial in reducing blowups by the increase in the per cent of miles of road with no blowups and the substantial decrease in the per cent of miles with four or more blowups per mile. The results of the Scheffe' Test in Tables 6a and 6b show that addition of a base significantly reduced blowup activity. As in the case of pavement design, concrete age is confounded with base to influence the results, and further study is suggested in this area.

Original Pavement Age

The age of the original pavement was identified early as a major variable. It would have been desirable to use equal intervals of age for analysis, but the distribution of ages of pavement sections was highly non-uniform, requiring the breakdown as shown in Table 7.

As pavement age increased, the per cent of miles of road with no blowups decreased, while roads with four or more blowups per mile increased. This trend continued for pavements up to 40 years old, at which point the trend reverses. Pavements over 45 years old seemed to show no preference for high or low blowup occurrence.

Table 5. Effect of Base on Blowups

Level	Range	Miles of Road				Per Cent of Miles		
		No Blowups	<4 Blowups Per Mile	≥ 4 Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	≥ 4 Blowups Per Mile
1	No Base	415.1	1361.0	1448.0	3224.1	12.8	42.3	44.9
2	Base	52.6	103.7	30.2	186.5	28.2	55.6	16.2

Table 6a. Ranking of Means (Base) for Scheffe' Significance Test

Level	Mean Number of Blowups Per Mile	Number of Observations	Standard Error of the Mean
1	1.7731	1081	.0416
2	0.8726	81	.1016

Table 6b. Results of Scheffe' Significance Test for Effect of Base

i	j	$Y_i - Y_j$	"C" Factor	Significant
1	2	.8065	.3032	x

Table 7. Effect of Original Pavement Age on Blowups

Level	Age in Years	Miles of Road				Per Cent of Miles		
		No Blowups	<4 Blowups Per Mile	≥4 Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	≥4 Blowups Per Mile
1	10-19	3.5	3.8	0.0	7.3	48.0	52.0	0.0
2	20-29	122.0	391.0	191.2	711.8	17.2	55.0	26.8
3	30-34	82.3	323.6	300.9	706.8	11.6	45.8	42.6
4	35-39	89.6	552.5	630.5	1272.6	7.0	43.4	49.6
5	40-44	108.4	148.7	274.5	531.6	20.4	28.0	51.6
6	45-up	61.5	48.7	73.7	183.9	33.4	26.5	40.1

No great significance can be placed on the fact that sections 10 to 19 years old showed no severe blowup activity. More total miles in this level need to be surveyed as emphasized by the results of the Scheffe' Test shown in Tables 8a and 8b. These pavements had the lowest mean number of blowups per mile but were not declared significantly different from pavements 40 to 44 years old because so few observations were available. However, pavements 20 to 29 years old had significantly less blowups per mile than pavements 40 to 44 years old. Again the reversal in trend by very old pavements is brought out in Table 8a by their position in the ranking of means.

It has been emphasized that the three variables of pavement design, base, and original pavement age are confounded in affecting pavement performance.

Coarse Aggregate

The effect of coarse aggregate used in concrete pavements was investigated from two different standpoints. From Table 9 information concerning the type of coarse aggregate is discussed, while data in Table A5 deal with individual aggregate sources and their blowup performance. Only those sections built entirely from one source are included in Tables A5, A6, and A7, and the validity of any conclusions made from these tables is dependent upon the total miles of road built from each source.

The two basic types of aggregate, crushed stone and gravel, were evaluated in this study. Many roads were

Table 8a. Ranking of Means (Original Pavement Age) for Scheffe" Significance Test

Level	Mean Number of Blowups Per Mile	Number of Observations	Standard Error of the Mean
5	1.9438	353	.0659
4	1.6561	207	.0884
6	1.6443	307	.0846
3	1.5573	185	.1091
2	1.1466	100	.1119
1	0.7620	10	.3525

Table 8b. Results of Scheffe' Significance Test for Effect of Original Pavement Age

i	j	$Y_i - Y_j$	"C" Factor	Significant
5	1	1.1818	1.4313	
5	2	.7972	.5056	x
5	3	.3865	.4051	
5	6	.2995	.3482	
5	4	.2877	.3907	
4	1	.8941	1.4451	
4	2	.5095	.5435	
4	3	.0988	.4515	
4	6	.0118	.4014	
6	1	.8823	1.4342	
6	2	.4977	.5139	
6	3	.0870	.4154	

Table 8b. Continued

i	j	$Y_i - Y_j$	"C" Factor	Significant
3	1	.7953	1.4491	
3	2	.4107	.5540	
2	1	.3846	1.4803	

Table 9. Effect of Coarse Aggregate on Blowups

Level	Aggregate Type	Miles of Road				Per Cent of Miles		
		No Blowups	<4 Blowups Per Mile	≥ 4 Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	≥ 4 Blowups Per Mile
1	Stone	66.2	325.2	125.8	517.2	12.8	62.9	24.3
2	Gravel	217.4	541.9	756.1	1515.4	14.3	35.8	49.9
3	Combination	54.7	285.0	264.8	604.5	9.0	47.1	43.9
4	Unknown	129.3	312.5	331.4	773.2	16.7	40.5	42.8

built with a combination of stone and gravel, and for many roads no information was available as to the type of aggregate used.

From Table 9 two conclusions can be drawn. First, no substantial difference existed between types of aggregate in providing roads with no blowups. Next, stone seemed to be somewhat superior in reducing the severity of blowup occurrence (more than four per mile) but, on the other hand, gravel showed a higher per cent of miles with less than four blowups per mile. Results of the Scheffe' Test in Table 10b indicate that no significant differences existed among aggregate types in blowup performance.

Data in Table A5 presents results of an investigation into the performance of individual sources of coarse aggregate used by the state of Indiana. This table ia a numerical ordering of sources showing the total miles of road built entirely from that source, as well as the breakdown of those miles into the three blowup groups based on the number of blowups per mile. Table A6 ranks the sources of aggregate according to the per cent of miles of road with no blowups. This table permits one to quickly pick out those sources giving good performance. A similar ranking is presented in Table A7 on the basis of per cent of miles with four or more blowups per mile. A cutoff point of 20 per cent was used for each table and in some cases a specific source appears in both tables.

Table 10a. Ranking of Means (Coarse Aggregate) for Scheffe' Significance Test

Level	Mean Number of Blowups Per Mile	Number of Observations	Standard Error of the Mean
3	1.8657	159	.1044
4	1.7329	431	.0788
2	1.6583	509	.0581
1	1.3891	153	.1063

Table 10b. Results of Scheffe' Significance Test for Effect of Coarse Aggregate

i	j	$Y_i - Y_j$	"C" Factor	Significant
3	1	.4766	.4289	x
3	2	.2074	.3440	
3	4	.1328	.3637	
4	1	.3438	.3685	
4	2	.0746	.2650	
2	1	.1946	.3491	

It can be concluded from these tables that the source of coarse aggregate can very definitely influence blowup activity. Since there are many more gravel sources than stone sources, nothing can be said about the type of aggregate, both types showing good and bad performance. Investigation of these good and bad sources is greatly needed to determine the properties of the aggregates which are different and thus affect blowups.

Subgrade Type

To study the effect of various types of subgrade on blowup activity, the predominant soil type for each section of road was determined from a soils map of Indiana (9). Thirteen soil types exist but for purposes of this analysis, they were divided into four basic groups: (1) sands and gravels, (2) glacial drift, lacustrine and loess deposits, (3) terminal morraines, and (4) residual soils derived from limestone, sandstone, and shale.

Two conclusions can be drawn from Table 11. Fewer blowups were observed in pavements whose subgrade was residual, while terminal morraines showed the highest frequency. The Scheffe' Test results in Table 12b showed these two soil types to be significantly different. Generally, relatively little differences were shown for the other soils. Terminal morraines occur in the central and northern parts of the state whereas residual soils are restricted to the southern portion.

Table 11. Effect of Subgrade Type on Blowups

Level	Subgrade Type	Miles of Road				Per Cent of Miles		
		No Blowups	<4 Blowups Per Mile	≥ 4 Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	≥ 4 Blowups Per Mile
1	Sand, Gravel	89.6	203.7	260.0	553.3	16.2	36.8	47.0
2	Silt, Clay	272.6	866.4	839.0	1978.0	13.8	43.8	42.4
3	Morraine	78.9	189.9	314.4	583.2	13.5	32.6	53.9
4	Residual	26.4	204.3	64.4	295.1	8.9	69.2	21.8

Table 12a. Ranking of Means (Subgrade Type) for Scheffe' Significance Test

Level	Mean Number of Blowups Per Mile	Number of Observations	Standard Error of the Mean
3	1.8251	201	.1007
1	1.7672	207	.1083
2	1.6422	685	.0497
4	1.2657	69	.1171

Table 12b. Results of Scheffe' Significance Test for Effect of Subgrade Type

i	j	$Y_i - Y_j$	"C" Factor	Significant
3	4	.5558	.5285	x
3	2	.1793	.3038	
3	1	.0543	.3751	
1	4	.5015	.5266	
1	2	.1250	.3004	
2	4	.3765	.4784	

District

The highway districts were chosen as a factor to study the effect of pavement location on blowups. It should be pointed out that, in so far as location is concerned, this is a broad classification which could influence blowup occurrence. This factor warrants further investigation.

Table 13 shows an increase in the severity of blowup activity from the southern portion of the state to the northern, with the LaPorte and Ft. Wayne districts having over half of their roads with four or more blowups per mile, and the Greenfield district had nearly 50 per cent in the same group. Many possible reasons for this trend exist but it is felt that two in particular are of importance. First of all the winter maintenance performed by the northern districts is much heavier. More sanding and salting of pavements is done to keep larger traffic volumes moving, resulting in accelerated deterioration of the concrete as well as clogged joints. Secondly, this variable is confounded with subgrade type; the northern third of the state is glaciated whereas the soils in the southern third of the state are in great part residual derived from rock in place.

The Greenfield district had almost one fourth of its roads with no blowups, substantially better than any other district. The Scheffe' Test in Table 14b concludes that the LaPorte district is significantly higher in average blowups per mile than the Crawfordsville, Vincennes, and Seymour districts.

Table 13. Effect of District on Blowups

Level	District	Miles of Road				Per Cent of Miles		
		No Blowups	<4 Blowups Per Mile	≥ 4 Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	≥ 4 Blowups Per Mile
1	LaPorte	41.6	196.7	334.1	572.4	7.2	34.4	58.4
2	Ft. Wayne	94.1	205.1	333.4	632.6	14.8	32.4	52.8
3	C'ville	88.7	308.7	223.6	621.0	14.3	49.7	36.0
4	Greenfield	157.8	165.6	321.1	644.5	24.5	25.7	49.8
5	Vincennes	23.0	280.2	135.4	438.6	5.2	63.9	30.9
6	Seymour	62.5	308.3	130.5	501.3	12.4	61.5	26.0

Table 14a. Ranking of Means (District) for Scheffe' Significance Test

Level	Mean Number of Blowups Per Mile	Number of Observations	Standard Error of the Mean
1	2.0371	233	.1021
2	1.7745	204	.0851
4	1.7306	265	.0937
5	1.4790	116	.0955
3	1.4083	171	.0922
6	1.3752	173	.0892

Table 14b. Results of Scheffe' Significance Test for Effect of District

i	j	$Y_i - Y_j$	"C" Factor	Significant
1	6	.6619	.4478	x
1	3	.6288	.4493	x
1	5	.5581	.5070	x
1	4	.3065	.4007	
1	2	.2626	.4278	
2	6	.3993	.4612	
2	3	.3662	.4646	
2	5	.2955	.5189	
2	4	.0439	.4156	
4	6	.3554	.4361	
4	3	.3223	.4377	
4	5	.2516	.4967	

Table 14b. Continued

i	j	$Y_i - Y_j$	"C" Factor	Significant
5	6	.1038	.5354	
5	3	.0707	.5367	
3	6	.0331	.4811	

Shoulder Type

In previous research, it was suggested that shoulders were a source of infiltration of incompressible material into joints. To investigate this factor, the predominant type of shoulder for each section of road was recorded during the field survey. The following conclusions are made from Table 15.

Paved shoulders have significantly reduced the per cent of miles with four or more blowups per mile when compared to gravel or turf shoulders. Twenty-five per cent of all roads with paved shoulders had no blowups, while gravel and turf shoulders are virtually indistinguishable from a performance viewpoint. The Scheffe' Test in Table 16b substantiates these conclusions.

First Overlay Age

The factor of first overlay age was considered in this study with the intent of finding when blowups begin to appear after a road has been resurfaced. Only roads with one overlay were considered.

As seen in Table 17, blowups begin to appear very soon and in serious proportions between three and five years of overlay age. This is brought out by the large jump in the per cent of miles with four or more blowups per mile and the simultaneous drop in no blowup percentage from pavements two years old or less to pavements three to five years old. Eighty-three per cent of the roads had some blowup activity

Table 15. Effect of Shoulder Type on Blowups

Level	Shoulder Type	Miles of Road: No Blowups	Miles of Road: <4 Blowups Per Mile	Miles of Road: $\geq$4 Blowups Per Mile	Miles of Road: Total Miles	Per Cent of Miles: No Blowups	Per Cent of Miles: <4 Blowups Per Mile	Per Cent of Miles: $\geq$4 Blowups Per Mile
1	Paved	148.6	267.7	174.0	590.3	25.2	45.3	29.5
2	Gravel	216.8	799.7	871.5	1888.0	11.5	42.4	46.1
3	Turf	102.3	397.2	432.6	932.1	10.9	42.7	46.4

Table 16a. Ranking of Means (Shoulder Type) for Scheffe' Significance Test

Level	Mean Number of Blowups Per Mile	Number of Observations	Standard Error of the Mean
2	1.8238	658	.0534
3	1.8133	253	.0846
1	1.1369	251	.0767

Table 16b. Results of Scheffe' Significance Test for Effect of Shoulder Type

i	j	$Y_i - Y_j$	"C" Factor	Significant
2	1	.6869	.2413	x
2	3	.0105	.2413	
3	1	.6764	.2906	x

Table 17. Effect of First Overlay Age on Blowups

Level	First Overlay Age in Years	Miles of Road				Per Cent of Miles		
		No Blowups	<4 Blowups Per Mile	≥4 Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	≥4 Blowups Per Mile
1	0-2	4.6	26.3	0.7	31.6	14.6	83.2	2.2
2	3-5	7.2	73.8	39.7	120.7	5.9	61.2	32.9
3	6-10	70.8	171.9	169.2	411.9	17.2	41.7	41.1
4	11-20	101.2	322.7	378.1	802.0	12.6	40.2	47.2
5	over 21	24.1	41.0	34.5	99.6	24.1	41.3	34.6

Table 18a. Ranking of Means (First Overlay Age) for Scheffe' Significance Test

Level	Mean Number of Blowups Per Mile	Number of Observations	Standard Error of the Mean
4	1.9314	244	.0888
2	1.7545	40	.2192
5	1.4905	45	.2871
3	1.4543	115	.1069
1	0.7875	15	.2091

Table 18b. Results of Scheffe' Significance Test for Effect of First Overlay Age

i	j	$Y_i - Y_j$	"C" Factor	Significant
4	1	1.1339	1.1015	x
4	3	.4679	.4683	x
4	5	.4309	.6717	
4	2	.1669	.7063	
2	1	.9670	1.2536	
2	3	.3002	.7600	
2	5	.2640	.8990	
5	1	.7030	1.2345	
5	3	.0362	.7280	
3	1	.6669	1.1367	

before the end of the second year. As the age of the first overlay increases, so does the per cent of roads with more than four blowups per mile. This trend continues for ages up to 20 years.

Total Overlay Thickness

The total overlay thickness was considered to be an important factor from an economic viewpoint. It has been hypothesized by some that use of relatively thick overlays may reduce blowup activity. If this were true then engineers could weigh this reduction in activity against the added cost of using a thicker overlay. Table 19 shows data as a function of overlay thickness. It should be recalled that age of overlay has an interacting effect here since the thicker overlays are older and represent more than one overlay application. No correlation could be found between overlay thickness and amount of blowups.

Remaining Factors

There were an additional 13 factors in this study which were judged to have some influence on blowups. No attempt was made to analyze these statistically. These data, however, are presented in the appendix for reference.

Table 19. Effect of Total Overlay Thickness on Blowups

Level	Total Overlay Thickness (Inches)	Miles of Road				Per Cent of Miles		
		No Blowups	<4 Blowups Per Mile	≥4 Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	≥4 Blowups Per Mile
1	0.0-0.9"	102.0	390.8	390.2	883.0	11.6	44.2	44.2
2	1.0-1.9	162.7	641.7	696.6	1501.0	10.8	42.8	46.4
3	2.0-2.9	101.2	226.6	240.7	568.5	17.8	39.9	42.3
4	over 3.0	101.6	205.5	150.6	457.7	22.2	44.9	32.9

Table 20a. Ranking of Means (Total Overlay Thickness) for Scheffe' Significance Test

Level	Mean Number of Blowups Per Mile	Number of Observations	Standard Error of the Mean
2	1.7529	487	.0605
1	1.7105	459	.0654
3	1.4418	190	.0947
4	1.0296	22	.2790

Table 20b. Results of Scheffe' Significance Test for Effect of Total Overlay Thickness

i	j	$Y_i - Y_j$	"C" Factor	Significant
2	4	.7233	.9093	
2	3	.3111	.3568	
2	1	.6424	.2714	
1	4	.6809	.9105	
1	3	.2687	.3598	
3	4	.4122	.9395	

SUMMARY

This research was conducted with two primary objectives, first to make a statewide survey of blowups and to catalogue this information, and second, to determine what the major factors are that contribute to blowups of resurfaced concrete pavements. The following summarizes the data presented in previous sections of this report. The results presented here are the results of a field study.

1. In so far as influencing blowups on resurfaced concrete pavements is concerned, the factors of pavement design, base, and age of the original pavement are all interrelated. The data suggest that present design and construction practices are superior to those of the past in preventing blowups.

(a) All other factors being equal, the data indicate that original pavement design is a major factor as a contributor to blowups. For example, pavements built between 1941 and 1944 with short joint spacing and no steel depart from the previously established trend of improving performance as design changes were made. These pavements have the highest mean number of blowups per mile and the lowest per cent of miles of road with no blowups.

(b) The addition of a granular base beneath concrete pavements in 1946 has substantially improved their

performance. This is due, at least in part, to the increased drainage capability provided by the base, thus reducing the moisture present beneath the pavement.

(c) Blowup activity increased as the age of the original pavement increased. This trend continued for pavements up to 40 years old with older pavements showing no preference for high or low blowup occurrence.

2. Crushed stone as a coarse aggregate in concrete pavements has shown slightly better performance overall as compared to gravel. However, both types have shown variable performance. The actual source of the material should be given primary consideration when choosing materials.

3. Pavements built on subgrades of residual soils showed fewer blowups than those on other soil types, and those built through terminal morraines had the highest blowup occurrences. Other soil types showed little differences in performance.

4. Weather, winter maintenance (salting and sanding), and soils seem to interact in the district factor, with blowups occurring at higher frequencies in the northern portion of the state than in the southern part.

5. Paved shoulders are significant in reducing blowups.

6. Blowup activity starts very soon after the pavement is overlaid, and the percentage of roads with more than four blowups per mile increased with age of the overlay.

7. Overlay thickness had little effect on blowup occurrence.

SUGGESTIONS FOR FURTHER RESEARCH

In conducting this investigation, needed areas of research into the blowup phenomenon have become apparent. The following items are suggested for further study.

1. Eliminate the confounding (refer to page 30 for definition) among factors influencing blowup activity and investigate the interactions of the unconfounded factors in addition to their main effects. This thesis investigated only the main effects of the factors. One means of attacking this general problem is given by the pavement design and year constructed example on page 30. The same is true for district and subgrade type. Use the age of first overlay and shoulder type as the third and fourth variables and investigate all possible two and three way interactions among these factors.

2. The basic physical properties of various sources of aggregate used on roads with good and poor performance should be compared to isolate which properties are significant.

3. Several pavements with single overlay ages of more than 20 years have given excellent performance. These should be studied closely to find out why.

4. The effect of maintenance, especially winter maintenance, should be investigated to determine its influence on blowup occurrence.

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APPENDIX

Table Al. Blowup Study Card Code

Card Column	Variable	Code	Description	Source of Data
1-5	Card Number			
6	Route Class	1	Interstate Highways	Road-life
		2	U.S. Primary Routes	
		3	State Highways	
7-9	Route Number			
10	Direction of Travel	1	Northbound	Road-life
		2	Eastbound	
		3	Southbound	
		4	Westbound	
		5	Dual lane	
		6	Alternate route	
11	State Highway District	1	LaPorte	Road-life
		2	Ft. Wayne	
		3	Crawfordsville	
		4	Greenfield	
		5	Vincennes	
		6	Seymour	
12-13	County	1	Adams	Road-life
		2	Allen	
		3	Bartholomew	
		4	Benton	
		5	Blackford	
		6	Boone	
		7	Brown	
		8	Carroll	
		9	Cass	

Table Al. Continued

Card Column	Variable	Code	Description	Source of Data
		10	Clark	
		11	Clay	
		12	Clinton	
		13	Crawford	
		14	Daviess	
		15	Dearborn	
		16	Decatur	
		17	Dekalb	
		18	Delaware	
		19	Dubois	
		20	Elkhart	
		21	Fayette	
		22	Floyd	
		23	Fountain	
		24	Franklin	
		25	Fulton	
		26	Gibson	
		27	Grant	
		28	Greene	
		29	Hamilton	
		30	Hancock	
		31	Harrison	
		32	Hendricks	
		33	Henry	
		34	Howard	
		35	Huntington	
		36	Jackson	
		37	Jasper	
		38	Jay	
		39	Jefferson	
		40	Jennings	
		41	Johnson	

Table A1. Continued

Card Column	Variable	Code	Description	Source of Data
		42	Knox	
		43	Kosciusko	
		44	Lagrange	
		45	Lake	
		46	LaPorte	
		47	Lawrence	
		48	Madison	
		49	Marion	
		50	Marshall	
		51	Martin	
		52	Miami	
		53	Monroe	
		54	Montgomery	
		55	Morgan	
		56	Newton	
		57	Noble	
		58	Ohio	
		59	Orange	
		60	Owen	
		61	Parke	
		62	Perry	
		63	Pike	
		64	Porter	
		65	Posey	
		66	Pulaski	
		67	Putnam	
		68	Randolph	
		69	Ripley	
		70	Rush	
		71	St. Joseph	
		72	Scott	
		73	Shelby	

Table Al. Continued

Card Column	Variable	Code	Description	Source of Data
		74	Spencer	
		75	Starke	
		76	Steuben	
		77	Sullivan	
		78	Switzerland	
		79	Tippecanoe	
		80	Tipton	
		81	Union	
		82	Vanderburg	
		83	Vermillion	
		84	Vigo	
		85	Wabash	
		86	Warren	
		87	Warrick	
		88	Washington	
		89	Wayne	
		90	Wells	
		91	White	
		92	Whitley	
14-18	Section Length		Nearest 1/1000 mile	Road-life
19-20	Concrete Construction Date		Year	Road-life
21-22	Concrete Width		Feet	Road-life
23-25	Concrete Thickness		Edge-Center-Edge Inches	Road-life
26-27	Concrete Age		Years	Road-life
28	Base Present	1	No	Road-life
		2	Yes	

Table Al. Continued

Card Column	Variable	Code	Description	Source of Data
29	Coarse Aggregate	1	Crushed Stone	Construction Records
		2	Gravel	
		3	Combination	
		4	Unknown	
30-31	First Overlay Construction Date		Year	Road-life
32-33	First Overlay Width		Feet	Road-life
34-35	First Overlay Thickness		Nearest 1/10 inches	Road-life
36-37	First Overlay Age		Years	Road-life
38-39	Last Overlay Construction Date		Year	Road-life
40-41	Last Overlay Width		Feet	Road-life
42-43	Last Overlay Thickness		Nearest 1/10 inches	Road-life
44-45	Last Overlay Age		Years	Road-life
46	Number of Overlays			
47	Pavement Design	1	Prior to 1923	Original Standards and Specifications
		2	1923-1925	
		3	1926-1933	
		4	1934-1940	
		5	1941-1944	
		6	1945-1949	
		7	1950-1959	
		8	1960-Present	

Table A1. Continued

Card Column	Variable	Code	Description	Source of Data
48-49	Subgrade Type	01	Pourous Substrata	Reference (9)
		02	Sands	
		03	Lakebeds	
		04	Young Drift Till, Clays	
		05	Morraines	
		06	Sand, Gravel, Till	
		07	Old Drift Silts, Clays	
		08	Loess-silt	
		09	Limestone	
		10	Interbedded Limestone, Shale	
		11	Limestone, Sandstone, Shale	
		12	Sandstone and Some Shale	
		13	Interbedded Shale, Sandstone	
50	Normal Annual Precipitation	1	40-42 inches	Reference (12)
		2	38-40	
		3	34-36	
		4	36-38	
		5	34-36	
		6	38-40	
		7	40-42	
		8	42-44	
		9	44-46	
		0	42-44	
51	Mean Annual Snowfall	1	60-70 inches	Reference (12)
		2	50-60	
		3	40-50	
		4	30-40	
		5	20-30	
		6	10-20	
		7	0-10	

Table A1. Continued

Card Column	Variable	Code	Description	Source of Data
52	Mean Daily Maximum Temperature in July	1	82-84 degrees F	Reference (12)
		2	84-86	
		3	86-88	
		4	84-86	
		5	88-90	
		6	86-88	
		7	84-86	
		9	90-92	
		0	88-90	
53	Average Daily Traffic	1	0-999 Vehicles Per Day	ISHC Traffic Map, 1969
		2	1000-2499	
		3	2500-4999	
		4	5000-9999	
		5	10000 & over	
54-55	Total Overlay Thickness		Nearest 1/10 inches	
56	Drainage	1	Good	Subjective rating on site
		2	Fair	
		3	Poor	
57	Shoulder Type	1	Paved	Subjective rating on site
		2	Gravel	
		3	Turf	
58-59	Number of Blowups		One lane type one blowup	Subjective rating on site
60-61			One lane type two blowup	
62-63			One lane type one patch	
64-65			One lane type two patch	
66-67			One lane type three blowup	

Table A1. Continued

Card Column	Variable	Code	Description	Source of Data
68-69			Two lane type one blowup	
70-71			Two lane type two blowup	
72-73			Two lane type one patch	
74-75			Two lane type two patch	
76-77			Two lane type three blowup	

Table A2. Summary of Data

Level	Range	Miles of Road				Per Cent of Miles		
		No Blowups	<4 Blowups Per Mile	≥ 4 Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	≥ 4 Blowups Per Mile
			Original Concrete Width					
1	18'	239.7	669.1	818.3	1727.1	13.9	38.7	47.4
2	20'	125.3	483.3	524.7	1133.3	11.1	42.6	46.3
3	22'	102.8	312.2	135.1	549.1	18.2	57.2	24.6
			Original Concrete Thickness					
1	6"	23.3	108.7	54.5	186.5	12.5	58.3	29.2
2	7"	346.3	1232.7	1272.4	2851.4	12.2	43.2	44.6
3	8"	89.1	106.0	118.3	313.4	28.4	33.8	37.8
4	9"	9.0	17.1	32.8	58.9	15.3	29.0	55.7
			Original Pavement Age					
1	10-19	3.5	3.8	0.0	7.3	48.0	52.0	0.0
2	20-29	122.0	391.0	191.2	711.8	17.2	55.0	26.8
3	30-34	82.3	323.6	300.9	706.8	11.6	45.8	42.6
4	35-39	89.6	552.5	630.5	1272.6	7.0	43.4	49.6
5	40-44	108.4	148.7	274.5	531.6	20.4	28.0	51.6

Table A2. Continued

Level	Range	Miles of Road				Per Cent of Miles		
		No Blowups	<4 Blowups Per Mile	≥4 Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	≥4 Blowups Per Mile
6	45-up	61.5	48.7	73.7	183.9	33.4	26.5	40.1
				Base				
1	No Base	415.1	1361.0	1448.0	3224.1	12.8	42.3	44.9
2	Base	52.6	103.7	30.2	186.5	28.2	55.6	16.2
				Coarse Aggregate				
1	Stone	66.2	325.2	125.8	517.2	12.8	62.9	24.3
2	Gravel	217.4	541.9	756.1	1515.4	14.3	35.8	49.9
3	Combination	54.7	285.0	264.8	604.5	9.0	47.1	43.9
4	Unknown	129.3	312.5	331.4	773.2	16.7	40.5	42.8
				First Overlay Width				
1	20'	21.7	20.7	68.0	110.4	19.6	18.7	61.7
2	22'	61.5	137.7	125.2	324.4	18.9	42.4	38.7
3	24'	124.8	477.4	428.4	1030.6	12.1	46.3	41.6
				First Overlay Thickness				
1	0.0-0.5"	11.8	41.4	6.6	59.8	19.7	69.2	11.0

Table A2. Continued

Level	Range	Miles of Road				Per Cent of Miles		
		No Blowups	< 4 Blowups Per Mile	$\geqq$ 4 Blowups Per Mile	Total Miles	No Blowups	< 4 Blowups Per Mile	$\geqq$ 4 Blowups Per Mile
2	0.6-1.0	157.6	557.9	574.3	1289.8	12.2	43.2	44.6
3	1.1-1.5	13.2	11.9	20.4	45.5	29.0	26.2	44.8
4	1.6-2.0	1.0	3.5	11.4	15.9	6.3	22.0	71.7
5	over 2.1	24.4	21.0	8.9	54.3	44.9	38.7	16.4
				First Overlay Age				
1	0-2	4.6	26.3	0.7	31.6	14.6	83.2	2.2
2	3-5	7.2	73.8	39.7	120.7	5.9	61.2	32.9
3	6-10	70.8	171.9	169.2	411.9	17.2	41.7	41.1
4	11-20	101.2	322.7	378.1	802.0	12.6	40.2	47.2
5	over 21	24.1	41.0	34.5	99.6	24.1	41.3	34.6
				Second Overlay Width				
1	20'	8.7	22.1	54.5	85.3	10.2	25.9	63.9
2	22'	59.2	214.6	206.9	480.7	12.3	44.7	43.0
3	24'	76.3	434.4	457.3	968.0	7.9	44.9	47.2

Table A2. Continued

Level	Range	Miles of Road: No Blowups	Miles of Road: <4 Blowups Per Mile	Miles of Road: $\geqq 4$ Blowups Per Mile	Miles of Road: Total Miles	Per Cent of Miles: No Blowups	Per Cent of Miles: <4 Blowups Per Mile	Per Cent of Miles: $\geqq 4$ Blowups Per Mile
				Second Overlay Thickness				
1	0.0-0.5"	13.5	91.5	134.5	239.5	5.6	38.2	56.2
2	0.6-1.0	114.5	477.3	483.1	1074.9	10.6	44.5	44.9
3	1.1-1.5	11.6	90.3	82.4	184.3	6.3	49.0	44.7
4	1.6-2.0	4.2	11.9	18.6	34.7	12.1	34.2	53.6
5	Over 2.1	0.4	0.0	0.0	0.4	100.0	0.0	0.0
				Second Overlay Age				
1	0-2	28.5	87.7	63.1	179.3	15.9	48.9	35.2
2	3-5	29.2	113.8	187.9	330.9	8.8	34.4	56.8
3	6-10	60.5	374.1	281.0	715.6	8.4	52.3	39.3
4	11-20	26.0	80.8	186.5	293.3	8.9	27.5	63.6
5	over 21	4.0	14.5	5.3	23.8	16.8	60.9	22.3
				Average Daily Traffic				
1	0-2499	75.3	288.5	288.7	652.5	11.5	44.2	44.2
2	2500-4999	220.3	623.9	645.5	1489.7	14.8	41.9	43.3

Table A2. Continued

Level	Range	Miles of Road: No Blowups	Miles of Road: < 4 Blowups Per Mile	Miles of Road: ≥ 4 Blowups Per Mile	Miles of Road: Total Miles	Per Cent of Miles: No Blowups	Per Cent of Miles: < 4 Blowups Per Mile	Per Cent of Miles: ≥ 4 Blowups Per Mile
3	over 5000	172.1	552.1	543.8	1268.0	13.6	43.5	42.9
				Number of Overlays				
1	1	208.1	635.8	621.6	1465.5	14.2	43.4	42.4
2	2	144.3	671.1	718.6	1534.0	9.4	43.7	46.8
3	3	97.5	146.5	125.3	369.3	26.4	39.7	33.9
4	4	17.0	8.2	11.9	38.0	47.1	21.6	31.3
5	5	0.0	2.9	0.7	3.6	0.0	80.5	19.5
				District				
1	LaPorte	41.6	196.7	334.1	572.4	7.2	34.4	58.4
2	Ft. Wayne	94.1	205.1	333.4	632.6	14.8	32.4	52.8
3	C'ville	88.7	308.7	223.6	621.0	14.3	49.7	36.0
4	Greenfield	157.8	165.6	321.1	644.5	24.5	25.7	49.8
5	Vincennes	23.0	280.2	135.4	438.6	5.2	63.9	30.9
6	Seymour	62.5	308.3	130.5	501.3	12.4	61.5	26.0

Table A2. Continued

Level	Range	Miles of Road				Per Cent of Miles		
		No Blowups	< 4 Blowups Per Mile	≥ 4 Blowups Per Mile	Total Miles	No Blowups	< 4 Blowups Per Mile	≥ 4 Blowups Per Mile
				Drainage				
1	Good	110.0	232.9	170.3	513.2	21.4	45.4	33.2
2	Fair	265.2	1073.8	1073.1	2412.1	11.0	44.5	44.5
3	Poor	92.5	157.9	234.6	485.0	19.1	32.5	48.4
				Shoulder Type				
1	Paved	148.6	267.7	174.0	590.3	25.2	45.3	29.5
2	Gravel	216.8	799.7	871.5	1888.0	11.5	42.4	46.1
3	Turf	102.3	397.2	432.6	932.1	10.9	42.7	46.4
				Total Overlay Thickness				
1	0.0-0.9"	102.0	390.8	390.2	883.0	11.6	44.2	44.2
2	1.0-1.9	162.7	641.7	696.6	1501.0	10.8	42.8	46.4
3	2.0-2.9	101.2	226.6	240.7	568.5	17.8	39.9	42.3
4	over 3.0	101.6	205.5	150.6	457.7	22.2	44.9	32.9
				Pavement Design				
1	1919-1933	288.0	908.4	1158.0	2354.4	12.2	38.6	49.2

Table A2. Continued

Level	Range	Miles of Road				Per Cent of Miles		
		No Blowups	< 4 Blowups Per Mile	≥ 4 Blowups Per Mile	Total Miles	No Blowups	< 4 Blowups Per Mile	≥ 4 Blowups Per Mile
2	1934-1940	112.0	331.6	222.0	665.6	16.8	49.8	33.4
3	1941-1944	21.9	114.9	73.8	210.6	10.4	54.5	35.1
4	1945-1949	33.1	93.1	22.1	148.3	22.3	62.8	14.9
5	1950-1959	12.7	16.5	2.1	31.3	40.6	52.8	6.6
				Subgrade Type				
1	Sand, Gravel	89.6	203.7	260.0	553.3	16.2	36.8	47.0
2	Silt, Clay	272.6	866.4	839.0	1978.0	13.8	43.8	42.4
3	Morraine	78.9	189.9	314.4	583.2	13.5	32.6	53.9
4	Residual	26.4	204.3	64.4	295.1	8.9	69.2	21.8
				Normal Annual Precipitation				
1	34-37"	145.4	413.3	677.0	1235.7	11.8	33.4	54.8
2	38-41	257.6	569.3	590.8	1417.7	18.2	40.1	41.7
3	42-46	64.5	481.8	210.1	756.4	8.5	63.7	27.8
				Mean Annual Snowfall				
1	0-19"	306.3	938.8	542.1	1787.2	17.1	52.5	30.4

Table A2. Continued

Level	Range	Miles of Road: No Blowups	Miles of Road: <4 Blowups Per Mile	Miles of Road: $\geqq 4$ Blowups Per Mile	Miles of Road: Total Miles	Per Cent of Miles: No Blowups	Per Cent of Miles: <4 Blowups Per Mile	Per Cent of Miles: $\geqq 4$ Blowups Per Mile
2	20-29	109.5	365.2	674.1	1148.8	9.5	31.8	58.7
3	over 30	52.3	160.5	261.8	474.6	11.0	33.8	55.2
			Mean Daily July Temperature					
1	82-85 $^{\circ}$F	55.6	90.9	211.7	358.2	15.5	25.4	59.1
2	86-87	189.9	479.3	574.8	1243.1	15.2	28.6	46.2
3	over 88	223.9	894.1	691.4	1809.4	12.4	49.4	38.2

Table A3. Ranking of Means for Scheffe' Significance Tests

Level	Mean Number of Blowups Per Mile	Number of Observations	Standard Error of the Mean
	District		
1	2.0371	233	.1021
2	1.7745	204	.0851
4	1.7306	265	.0937
5	1.4790	116	.0955
3	1.4083	171	.0922
6	1.3752	173	.0892
	Original Pavement Age		
5	1.9438	353	.0659
4	1.6561	207	.0884
6	1.6443	307	.0846
3	1.5573	185	.1091
2	1.1466	100	.1119
1	0.7620	10	.3525
	Base		
1	1.7731	1081	.0416
2	0.8726	81	.1016
	Coarse Aggregate		
3	1.8657	159	.1044
4	1.7329	341	.0788
2	1.6583	509	.0581
1	1.3891	153	.1063

Table A3. Continued

Level	Mean Number of Blowups Per Mile	Number of Observations	Standard Error of the Mean
	First Overlay Age		
4	1.9314	244	.0888
2	1.7545	40	.2192
5	1.4905	45	.2871
3	1.4543	115	.1069
1	0.7875	15	.2091
	Total Overlay Thickness		
2	1.7529	487	.0605
1	1.7105	459	.0654
3	1.4418	190	.0947
4	1.0296	22	.2790
	Pavement Design		
3	2.0128	93	.1710
1	1.8227	746	.0494
2	1.3270	248	.0784
4	0.9379	57	.1263
5	0.8161	18	.2265
	Subgrade Type		
3	1.8251	201	.1007
1	1.7672	207	.1083
2	1.6422	685	.0497
4	1.2657	69	.1171

Table A3. Continued

Level	Mean Number of Blowups Per Mile	Number of Observations	Standard Error of the Mean
	Shoulder Type		
2	1.8238	658	.0534
3	1.8133	253	.0846
1	1.1369	251	.0767

Table A4. Results of Scheffe' Significance Tests

i	j	$Y_i - Y_j$	"C" Factor	Significant
		District		
1	6	.6619	.4478	x
1	3	.6288	.4493	x
1	5	.5581	.5070	x
1	4	.3065	.4007	
1	2	.2626	.4278	
2	6	.3993	.4612	
2	3	.3662	.4626	
2	5	.2955	.5189	
2	4	.0439	.4156	
4	6	.3554	.4361	
4	3	.3223	.4377	
4	5	.2516	.4967	
5	6	.1038	.5354	
5	3	.0707	.5367	
3	6	.0331	.4811	
		Original Pavement Age		
5	1	1.1818	1.4313	x
5	2	.7972	.5056	
5	3	.3865	.4051	
5	6	.2995	.3482	
5	4	.2877	.3907	
4	1	.8941	1.4451	
4	2	.5095	.5435	

Table A4. Continued

i	j	$Y_i - Y_j$	"C" Factor	Significant
4	3	.0988	.4515	
4	6	.0118	.4014	
6	1	.8823	1.4342	
6	2	.4977	.5319	
6	3	.0870	.4154	
3	1	.7953	1.4491	
3	2	.4107	.5540	
2	1	.3846	1.4803	
		Base		
1	2	.8605	.3032	
		Coarse Aggregate		
3	1	.4766	.4289	
3	2	.2074	.3440	
3	4	.1328	.3637	
4	1	.3438	.3685	
4	2	.0746	.2650	
2	1	.1946	.3491	
		First Overlay Age		
4	1	1.1339	1.1015	x
4	3	.4679	.4683	x
4	5	.4309	.6717	
4	2	.1669	.7063	
2	1	.9670	1.2536	
2	3	.3002	.7600	

Table A4. Continued

i	j	$Y_i - Y_j$	"C" Factor	Significant
2	5	.2640	.8990	
5	1	.7030	1.2345	
5	3	.0362	.7280	
3	1	.6669	1.1367	
		Total Overlay Thickness		
2	4	.7233	.9093	
2	3	.3111	.3568	
2	1	.6424	.2714	
1	4	.6809	.9105	
1	3	.2687	.3598	
3	4	.4122	.9395	
		Pavement Design		
3	5	1.1967	1.0545	x
3	4	1.0749	.6888	x
3	2	.6858	.4979	x
3	1	.1901	.4503	
1	5	1.0066	.9768	x
1	4	.8848	.5627	x
1	2	.4957	.3001	x
2	5	.5109	.9996	
2	4	.3891	.6015	
4	5	.1218	1.1071	

Table A4. Continued

i	j	$Y_i - Y_j$	"C" Factor	Significant
		Subgrade Type		
3	4	.5558	.5285	x
3	2	.1793	.3038	
3	1	.0543	.3751	
1	4	.5015	.5266	
1	2	.1250	.3004	
2	4	.3765	.4784	
		Shoulder Type		
2	1	.6869	.2413	x
2	3	.0105	.2413	
3	1	.6764	.2906	x

Table A5. Evaluation of Coarse Aggregate Sources

Source	Miles of Road				Per Cent of Miles		
	No Blowups	<4 Blowups Per Mile	$\geqq$4 Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	$\geqq$4 Blowups Per Mile
1012	0.00	3.69	2.91	6.60	0.0	56.0	44.0
2011	0.00	0.42	0.00	0.42	0.0	100.0	0.0
3012	2.91	8.43	20.83	32.17	8.9	26.2	64.9
3052	1.09	0.00	4.67	5.66	19.2	0.0	80.8
5011	0.00	2.85	0.00	2.85	0.0	100.0	0.0
8041	0.00	0.00	8.43	8.43	0.0	0.0	100.0
9012	0.00	2.02	8.76	10.78	0.0	18.8	81.2
9031	1.97	20.88	11.23	34.08	5.8	61.2	33.0
9041	1.75	5.68	14.02	21.45	8.0	26.5	65.5
10011	0.00	4.79	0.00	4.79	0.0	100.0	0.0
10072	0.90	11.64	0.47	13.01	6.9	89.5	3.6
10081	0.00	11.54	1.28	12.82	0.0	90.0	10.0
10092	0.00	14.46	0.00	14.46	0.0	100.0	0.0
13012	2.04	19.50	0.00	21.54	9.4	90.6	0.0

Table A5. Continued

Source	Miles of Road				Per Cent of Miles		
	No Blowups	< 4 Blowups Per Mile	≥ 4 Blowups Per Mile	Total Miles	No Blowups	< 4 Blowups Per Mile	≥ 4 Blowups Per Mile
17021	0.00	0.00	3.95	3.95	0.0	0.0	100.0
18011	9.60	0.00	0.00	9.60	100.0	0.0	0.0
18021	0.00	9.48	3.94	13.42	0.0	70.6	29.4
18071	0.00	0.00	11.83	11.83	0.0	0.0	100.0
20021	0.00	0.00	4.85	4.85	0.0	0.0	100.0
20041	3.95	0.00	0.00	3.95	100.0	0.0	0.0
21011	2.20	5.73	27.98	35.91	6.2	15.9	77.9
22011	7.42	10.17	1.82	19.41	38.2	52.5	9.3
23011	1.28	0.76	24.92	26.96	4.8	2.7	92.5
23021	0.00	8.45	0.00	8.45	0.0	100.0	0.0
23031	3.41	3.15	0.00	6.56	48.0	52.0	0.0
24011	0.00	8.02	0.00	8.02	0.0	100.0	0.0
24021	0.00	4.37	0.00	4.37	0.0	100.0	0.0
24051	0.00	3.24	0.00	3.24	0.0	100.0	0.0

Table A5. Continued

Source	Miles of Road				Per Cent of Miles		
	No Blowups	<4 Blowups Per Mile	≥4 Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	≥4 Blowups Per Mile
27022	0.00	0.00	3.86	3.86	0.0	0.0	100.0
28011	1.22	0.00	0.00	1.22	100.0	0.0	0.0
29011	0.00	1.58	7.86	9.44	0.0	16.7	83.3
30031	0.00	5.44	0.00	5.44	0.0	100.0	0.0
31012	0.00	2.43	0.00	2.43	0.0	100.0	0.0
35022	7.31	10.08	0.00	17.39	42.0	58.0	0.0
35041	7.83	1.73	0.00	9.56	81.9	18.1	0.0
35081	0.00	0.00	6.75	6.75	0.0	0.0	100.0
39032	0.00	0.00	.78	.78	0.0	0.0	100.0
40032	0.00	.41	0.00	.41	0.0	100.0	0.0
42031	0.00	4.18	5.06	9.24	0.0	45.2	54.8
43011	9.06	0.00	0.00	9.06	100.0	0.0	0.0
43021	1.06	10.82	0.00	11.88	9.0	91.0	0.0
45013	0.00	4.22	8.30	12.52	0.0	33.8	66.2

Table A5. Continued

Source	Miles of Road				Per Cent of Miles		
	No Blowups	<4 Blowups Per Mile	≥ 4 Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	≥ 4 Blowups Per Mile
47022	2.58	15.38	0.00	17.96	14.4	85.6	0.0
47032	.21	0.00	5.30	5.51	3.8	0.0	96.2
48011	6.71	0.00	44.23	50.94	13.1	0.0	86.9
48021	.73	0.00	14.66	15.39	4.8	0.0	95.2
49011	8.40	48.44	47.64	104.48	8.2	46.3	45.5
49091	0.00	3.01	8.39	11.40	0.0	26.5	73.5
49101	0.00	15.16	10.44	25.60	0.0	59.2	40.8
49111	2.37	0.00	13.16	15.53	15.4	0.0	84.6
49141	0.00	11.70	0.00	11.70	0.0	100.0	0.0
49151	16.03	5.13	9.27	30.43	52.7	16.9	30.4
52011	0.00	0.00	7.52	7.52	0.0	0.0	100.0
52021	0.00	2.99	15.13	18.12	0.0	16.5	83.5
55011	0.00	1.43	0.00	1.43	0.0	100.0	0.0
55021	0.00	0.00	2.32	2.32	0.0	0.0	100.0

Table A5. Continued

Source	Miles of Road				Per Cent of Miles		
	No Blowups	<4 Blowups Per Mile	≥ 4 Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	≥ 4 Blowups Per Mile
55041	0.00	0.00	2.24	2.24	0.0	0.0	100.0
56012	0.00	4.78	3.26	8.04	0.0	59.4	41.6
57011	0.00	4.74	21.87	26.61	0.0	17.8	82.2
57021	1.00	12.38	0.00	13.38	7.5	92.5	0.0
57031	0.00	0.00	8.77	8.77	0.0	0.0	100.0
60012	5.25	30.79	1.16	37.20	14.1	82.9	3.0
60021	0.00	1.76	0.00	1.76	0.0	100.0	0.0
60052	0.00	4.36	0.00	4.36	0.0	100.0	0.0
61011	1.89	0.00	15.70	17.59	10.8	0.0	89.2
62011	0.00	0.00	26.74	26.74	0.0	0.0	100.0
67012	4.81	90.68	3.29	98.78	4.9	91.8	3.3
67022	0.00	6.88	0.00	6.88	0.0	100.0	0.0
68031	0.00	0.00	14.75	14.75	0.0	0.0	100.0
69052	0.00	0.00	4.67	4.67	0.0	0.0	100.0

Table A 5. Continued

Source	Miles of Road				Per Cent of Miles		
	No Blowups	<4 Blowups Per Mile	$\geqq 4$ Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	$\geqq 4$ Blowups Per Mile
71012	.61	1.45	4.62	6.68	9.0	21.8	69.2
72011	26.39	0.00	7.87	34.26	77.0	0.0	23.0
72021	0.00	2.71	0.00	2.71	0.0	100.0	0.0
73011	.25	29.76	9.50	39.51	.7	75.3	24.0
74051	0.00	3.24	13.50	16.74	0.0	19.4	80.6
76031	0.00	0.00	3.04	3.04	0.0	0.0	100.0
77011	0.00	7.20	0.00	7.20	0.0	100.0	0.0
79011	5.32	33.07	52.35	90.74	5.8	36.5	57.7
82011	0.00	11.13	13.58	24.72	0.0	45.1	54.9
83011	0.00	4.76	5.29	10.05	0.0	47.4	52.6
83031	0.00	2.43	0.00	2.43	0.0	100.0	0.0
84011	9.71	14.63	2.54	26.88	36.1	54.5	9.4
84032	0.00	0.00	1.10	1.10	0.0	0.0	100.0
84031	9.93	7.55	16.20	33.68	29.5	22.5	48.0

Table A5. Continued

Source	Miles of Road				Per Cent of Miles		
	No Blowups	<4 Blowups Per Mile	≥4 Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	≥4 Blowups Per Mile
87021	0.00	0.00	8.18	8.18	0.0	0.0	100.0
89011	8.05	0.00	0.00	8.05	100.0	0.0	0.0
89021	14.36	23.46	31.84	69.66	20.6	33.7	45.7
89031	6.73	5.29	0.00	12.02	56.0	44.0	0.0
89061	0.00	1.81	2.06	3.87	0.0	46.8	53.2
90012	0.00	8.67	5.58	14.25	0.0	60.9	39.1
91002	8.37	18.54	3.32	30.23	27.5	60.9	11.6
93012	0.00	.40	1.23	1.63	0.0	24.5	75.5
93032	6.76	3.31	15.72	25.79	26.2	12.8	61.0
93041	1.10	7.54	1.37	10.01	13.6	75.4	11.0
93052	0.00	3.88	.44	4.32	0.0	89.9	10.1
93092	2.00	.83	0.00	2.83	70.7	29.3	0.0
93262	.30	1.17	0.00	1.47	20.5	79.5	0.0
94021	.30	0.00	.20	.50	60.0	0.0	40.0

Table A5. Continued

Source	Miles of Road				Per Cent of Miles		
	No Blowups	<4 Blowups Per Mile	$\geqq 4$ Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	$\geqq 4$ Blowups Per Mile
94081	0.00	8.59	1.73	10.32	0.0	83.2	16.8
94111	0.23	0.00	5.23	5.46	4.3	0.0	95.7
95051	0.00	0.00	9.05	9.05	0.0	0.0	100.0

Table A6. Ranking of Coarse Aggregate Sources by Per Cent of Miles of Road With No Blowups

Source	Miles of Road				Per Cent of Miles		
	No Blowups	<4 Blowups Per Mile	$\geqq 4$ Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	$\geqq 4$ Blowups Per Mile
18011	9.60	0.00	0.00	9.60	100.0	0.0	0.0
43011	9.06	0.00	0.00	9.06	100.0	0.0	0.0
89011	8.05	0.00	0.00	8.05	100.0	0.0	0.0
20041	3.95	0.00	0.00	3.95	100.0	0.0	0.0
28011	1.22	0.00	0.00	1.22	100.0	0.0	0.0
35041	7.83	1.73	0.00	9.56	81.9	18.1	0.0
72011	26.39	0.00	7.87	34.26	77.0	0.0	23.0
93092	2.00	0.83	0.00	2.83	70.7	29.3	0.0
94021	0.30	0.00	0.20	0.50	60.0	0.0	40.0
89031	6.73	5.29	0.00	12.02	56.0	44.0	0.0
49151	16.03	5.13	9.27	30.43	52.7	16.9	30.4
23031	3.41	3.15	0.00	6.56	48.0	52.0	0.0
35022	7.31	10.08	0.00	17.39	42.0	58.0	0.0
22011	7.42	10.17	1.82	19.41	38.2	52.4	9.4
84011	9.71	14.63	2.54	26.88	36.1	54.5	9.4

Table A6. Continued

Source	Miles of Road				Per Cent of Miles		
	No Blowups	<4 Blowups Per Mile	≥ 4 Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	≥ 4 Blowups Per Mile
84031	9.93	7.55	16.20	33.68	29.5	22.5	48.0
91002	8.37	18.54	3.32	30.23	27.5	60.9	11.6
93032	6.76	3.31	15.72	25.79	26.2	12.8	61.0
89021	14.36	23.46	31.84	69.66	20.6	33.7	45.7
93262	.30	1.17	0.00	1.47	20.5	79.5	0.0

Table A7. Ranking of Coarse Aggregate Sources by Per Cent of Miles of Road With Four or More Blowups Per Mile

Source	Miles of Road				Per Cent of Miles		
	No Blowups	<4 Blowups Per Mile	≥4 Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	≥4 Blowups Per Mile
62011	0.00	0.00	26.74	26.74	0.0	0.0	100.0
68031	0.00	0.00	14.75	14.75	0.0	0.0	100.0
18071	0.00	0.00	11.83	11.83	0.0	0.0	100.0
95051	0.00	0.00	9.05	9.05	0.0	0.0	100.0
57031	0.00	0.00	8.77	8.77	0.0	0.0	100.0
8041	0.00	0.00	8.43	8.43	0.0	0.0	100.0
87021	0.00	0.00	8.18	8.18	0.0	0.0	100.0
52011	0.00	0.00	7.52	75.2	0.0	0.0	100.0
35081	0.00	0.00	6.75	6.75	0.0	0.0	100.0
20021	0.00	0.00	4.85	4.85	0.0	0.0	100.0
69052	0.00	0.00	4.67	4.67	0.0	0.0	100.0
17021	0.00	0.00	3.95	3.95	0.0	0.0	100.0
27022	0.00	0.00	3.86	3.86	0.0	0.0	100.0
76031	0.00	0.00	3.04	3.04	0.0	0.0	100.0

Table A7. Continued

Source	Miles of Road: No Blowups	Miles of Road: <4 Blowups Per Mile	Miles of Road: ≥4 Blowups Per Mile	Miles of Road: Total Miles	Per Cent of Miles: No Blowups	Per Cent of Miles: <4 Blowups Per Mile	Per Cent of Miles: ≥4 Blowups Per Mile
55021	0.00	0.00	2.32	2.32	0.0	0.0	100.0
55041	0.00	0.00	2.24	2.24	0.0	0.0	100.0
84021	0.00	0.00	1.10	1.10	0.0	0.0	100.0
39032	0.00	0.00	.78	.78	0.0	0.0	100.0
47032	.21	0.00	5.30	5.51	3.8	0.0	96.2
94111	.23	0.00	5.23	5.46	4.3	0.0	95.7
48021	.73	0.00	14.66	15.39	4.8	0.0	95.2
23011	1.28	.76	24.92	26.96	4.8	2.7	92.5
61011	1.89	0.00	15.70	17.59	10.8	0.0	89.2
48011	6.71	0.00	44.23	50.94	13.1	0.0	86.9
49111	2.37	0.00	13.16	15.53	15.4	0.0	84.6
52021	0.00	2.99	15.13	18.12	0.0	16.5	83.5
29011	0.00	1.58	7.86	9.44	0.0	16.7	83.3
57011	0.00	4.74	21.87	26.61	0.0	17.8	82.2

Table A7. Continued

Source	Miles of Road				Per Cent of Miles		
	No Blowups	<4 Blowups Per Mile	≥4 Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	≥4 Blowups Per Mile
9012	0.00	2.02	8.76	10.78	0.0	18.8	81.2
3052	1.09	0.00	4.57	5.66	19.2	0.0	80.8
74051	0.00	3.24	13.50	16.74	0.0	19.4	80.6
21011	2.20	5.73	27.98	35.91	6.2	15.9	77.9
93012	0.00	.40	1.23	1.63	0.0	24.5	75.5
49091	0.00	3.01	8.39	11.40	0.0	26.5	73.5
71012	.62	1.45	4.62	6.68	9.0	21.8	69.2
45013	0.00	4.22	8.30	12.52	0.0	33.8	66.2
9041	1.75	5.68	14.02	21.45	8.0	26.5	65.5
3012	2.91	8.43	20.83	32.17	8.9	26.2	64.9
93032	6.76	3.31	15.72	25.79	26.2	12.8	61.0
79011	5.32	33.07	52.35	90.74	5.8	36.5	57.7
82011	0.00	11.13	13.58	24.71	0.0	45.1	54.9
42031	0.00	4.18	5.06	9.24	0.0	45.2	54.8

Table A7. Continued

Source	Miles of Road				Per Cent of Miles		
	No Blowups	<4 Blowups Per Mile	$\geqq 4$ Blowups Per Mile	Total Miles	No Blowups	<4 Blowups Per Mile	$\geqq 4$ Blowups Per Mile
89061	0.00	1.81	2.06	3.87	0.0	46.8	53.2
83011	0.00	4.76	5.29	10.05	0.0	47.4	52.6
84031	9.93	7.55	16.20	33.68	29.5	22.5	48.0
89021	14.36	23.46	31.84	69.66	20.6	33.7	45.7
49011	8.40	48.44	47.64	104.48	8.2	46.3	45.5
1012	0.00	3.69	2.91	6.60	0.0	56.0	44.0
56012	0.00	4.78	3.26	8.04	0.0	59.4	41.6
49101	0.00	15.16	10.44	25.59	0.0	59.2	40.8
94021	0.30	0.00	0.20	0.50	60.0	0.0	40.0
90012	0.00	8.67	5.58	14.25	0.0	60.9	39.1
9031	1.97	20.88	11.23	34.08	5.8	61.2	33.0
49151	16.03	5.13	9.27	30.43	52.7	16.9	30.4
18021	0.00	9.48	3.94	13.42	0.0	70.6	29.4
72011	26.39	0.00	7.89	34.26	77.0	0.0	23.0
73011	0.25	29.76	9.50	39.51	0.7	76.3	23.0